Description

Method and device for monitoring the particle concentration in a gas stream

The invention relates to a method and a device for monitoring the particle concentration in a gas stream, in particular of soot particles in the exhaust gas stream of an internal combustion engine.

The regulations relating to the emission of pollutants in motor vehicles are becoming increasingly strict. Measures for reducing the raw emission of the engine by optimizing the combustion process are often not sufficient in this context. In particular, diesel engines have high emissions of soot particles. These can be reduced by engine-side measures only at the cost of an increased emission of nitrogen oxides. It is therefore appropriate to reduce the emission of particles using exhaust gas post-treatment. Modern particle filter systems reach a very high efficiency level in this context with a deposition level of over 95%.

Owing to various causes, such a soot particle filter may be faulty or become faulty during operation such that it allows an increased quantity of soot particles to pass through. In order to be able to detect such a malfunction, it is necessary to measure the particle concentration in the gas stream downstream of the filter. For this purpose, a suitable sensor is expediently permanently installed in the exhaust gas section.

A method for determining the soot concentration in the exhaust gas which makes use of the electrical conductivity of soot particles, and a corresponding sensor are known, for example, from WO 84/003147 A1. The particles are deposited here on a carrier made of nonconductive material on whose surface two

metallic electrodes are mounted at a defined distance. In order to measure the soot load of the

sensor surface, a voltage in the range between 10 V and 100 V is applied to the sensor with an electrode spacing of less than 1 mm, and the current which flows between the two electrodes through the soot layer is measured. It is disadvantageous that the sensor has a low degree of sensitivity and a high degree of susceptibility to faults at very low particle concentrations since there has to be a continuous layer of soot between the electrodes for a current to flow at all. Since the electrodes are thus subjected directly to the exhaust gas stream and the soot particles, the service life of the sensor is also limited because of electrode erosion. Furthermore, DE 102 29 411 A1 discloses a method for determining the particle content in a gas stream in which an electrical field is applied between two electrodes of a sensor and the change in the field as a result of the particles is sensed.

The object of the present invention is to propose a method and a device for monitoring the particle concentration in a gas stream which are improved with respect to the aforesaid disadvantages.

This object is achieved by means of patent claim 1 with respect to the method, and by means of patent claim 5 with respect to the device.

The method according to the invention provides for a sensor which collects particles to be placed in a gas stream. The sensor is integrated as a capacitive element in an electro-magnetic resonant circuit. The resonant circuit is excited with an alternating voltage. The capacitive and resistive properties of the sensor are influenced here by the particle load of the sensor. As a result, at least one characteristic variable of the resonant circuit changes. This characteristic variable is determined as a reference value when the sensor is not loaded.

The change in the characteristic variable which is brought about by the particle load compared to the reference value is then determined.

Since the sensor is placed in the gas stream, it is subjected to the particles which are carried along by the gas stream, for which reason a greater or smaller amount of particles are deposited on the sensor depending on the total quantity of particles present in the gas stream. The quantity of deposited particles is thus a measure of the total particles contained in the gas stream, that is to say the particle concentration.

The electromagnetic resonant circuit is, for example, a series oscillating circuit which is constructed essentially from a capacitor and an inductor. Instead of the capacitor, the sensor is integrated into the resonant circuit. The equivalent circuit diagram of the sensor is here a parallel circuit composed of a capacitor and an ohmic resistor, the values of the capacitor and ohmic resistor changing as a result of the quantity of particles deposited on the sensor. Since the characteristic variables of the resonant circuit depend on the variables of the components contained therein, various characteristic variables of the entire resonant circuit, for example its resonant frequency, quality or overall impedance, change when the sensor is loaded with particles. Such a characteristic variable thus serves as a measure of the particle load of the sensor.

In the invention, even very small depositions of particles on the sensor already bring about initially small changes in the sensor properties, that is to say the values of its resistance or its capacitance. However, due to the effect of the amplification of the resonant circuit in the case of resonance, these depositions bring about large changes in suitable characteristic variables, for example the resonant frequency or the excessive increasing of the voltage at the capacitor. Since the properties of the sensor are measured indirectly by means of these characteristic variables, the sensitivity of method is increased significantly compared to a resistance measurement

with the known method. In addition, the method according to the invention also functions when there are very small accumulations on the sensor, even if there is still no "coherent" conductive particle layer on the sensor since the capacitive properties of the sensor already change even as a result of

very small quantities of particles, and even these changes can be sensed by the method.

In the invention, the resonant circuit is excited with alternating voltage with a fixed frequency and fixed amplitude and the voltage dropping across the sensor is determined as a characteristic variable. By means of this indirect measurement it is possible, owing to the excessive increasing of the voltage occurring at the capacitor, to determine the change in the resistance and the capacitance of the sensor significantly more precisely than via a direct measurement without a resonant circuit. The frequency of the exciting voltage only needs to lie approximately in the region of the resonant frequency of the resonant circuit.

As an alternative to the latter procedure, in the invention the resonant frequency of the resonant circuit is determined as a characteristic variable. This can take place in various ways, for example with the values sweeping through the frequency range in question, the locating of the maximum voltage at the sensor and the determination of the frequency associated with the maximum.

In a particularly simple way of implementing the invention, the frequency of the alternating voltage exciting the resonant circuit is tuned to the respective resonant frequency of the resonant circuit or adjusted in accordance with it. The resonant frequency is determined as a characteristic variable, which is particularly easy in this case since it corresponds to the frequency of the exciting voltage. Frequencies can generally be determined very precisely, as a result of which a very precise determination of the load-dependent sensor properties is possible in an indirect way. The frequency of the exciting voltage can also be tuned to the resonant frequency of the resonant circuit in a very easy way since in the case of

resonance the voltage which drops across the sensor does not change when the frequency is slightly detuned.

Usually, in an exhaust gas stream, in addition to particles there are often further substances, for example oil residues or hydrocarbons

with a high boiling point, which can become deposited on the sensor and disrupt the measurement. For this reason, in an advantageous development of the method, the sensor is heated during the determination of the characteristic variable to a temperature below the ignition temperature of the particles. If the temperature is sufficiently high, impurities which adhere to the sensor are thus removed, without however burning particles and thus also removing them. If the sensor is heated, for example, to a temperature of approximately 200°C, no condensate of oil residues or hydrocarbons with a high boiling point can become deposited on it and disrupt the measurement signal of the sensor. In the hot state of the sensor, such substances pass through the sensor without becoming deposited on it. However, the particles which are deposited on the sensor are retained and their concentration can still be determined.

If, before the characteristic variable is determined, the sensor is heated to a temperature above the ignition temperature of the particles, a further preferred variant of the method is obtained. The ignition temperature of the soot particles in the exhaust gas of diesel engines is, for example, approximately 550°C. The particles which are deposited on the sensor burn at this temperature and the entire particle load of the sensor is thus removed. After the sensor is heated, it is therefore free again of particles. A directly imminent determination of the characteristic variable thus again supplies a reference value for the sensor without loading. Since the reference value can be determined again at any time by means of this method variant, it is possible to compensate for fabrication tolerances of the sensor or for changes in its electrical properties over time.

An inventive device for carrying out the method according to the invention comprises a sensor which is placed in the exhaust gas stream. The latter is embodied in such a way that it

accumulates particles on itself from the gas stream which flows past it. It is integrated as a capacitive element into an

electromagnetic resonant circuit which is excited with alternating voltage. The sensor has a nonconductive base body made of porous material and two electrodes which are mounted on it spaced apart from one another. As a result of the electrodes which are insulated from one another, a capacitance is formed between them, for which reason the sensor has capacitive properties. When alternating voltage is applied to it, alternating current therefore flows through the sensor. When the sensor is loaded with particles, that is to say there is an accumulation of electrically conductive particles on the nonconductive body in the electrical field region of the electrodes, the electrical alternating voltage properties of the sensor change. When alternating voltage is applied to the sensor, for example electrical losses are generated in the particles, which is perceptible through a rise in the loss angle of the sensor capacitance as the particle load increases. In the equivalent circuit diagram of the sensor composed of a capacitor with a resistor connected in parallel, this causes the value of the ohmic resistance to drop.

Owing to the application of the alternating voltage, this does not require a continuous direct current path between the electrodes, which would correspond to a continuous layer of soot. The particles or particle layer also do not need to be in electrical contact with the electrodes. Even small quantities of deposited particles which do not form a closed conductive layer thus lead to a change in the electrical properties of the sensor. As already mentioned above, these very small changes in the electrical properties owing to the integration of the sensor into the resonant circuit when a few particles are deposited can be determined very precisely as a measure of the particle concentration present in the gas stream by means of the indirect measuring methods specified above.

Owing to the embodiment, in contrast to a base body made of a material with a smooth or dense surface, particles to be detected can become adhered significantly better to the sensor

and be secured or stored on it or in it. The greater number of adhering particles increases the sensitivity of the sensor significantly.

The porous base body is preferably composed of high-quality ceramic or quartz glass. This ensures that the sensor is stable with respect to temperature and robust in order to withstand the extreme ambient conditions in the exhaust gas stream of an internal combustion engine. Furthermore, the smallest quantities of particles which have become deposited thus also change the electrical properties of the sensor since the particles bring about significantly higher dielectric losses than the base body.

In the device according to the invention, owing to the integration of the sensor in a resonant circuit, there is - as mentioned above - no need for a direct current connection between the electrode and the conductive particles or conductive layer of soot. In one advantageous embodiment variant, the electrodes can therefore be embedded in the base body. The particles or the particle layer is then coupled capacitively to the electrodes. The embedding of the electrodes in the base body means that they are not directly subjected to the gas stream, which significantly lengthens their service life, and particularly in the case of an exhaust gas stream of an internal combustion engine they are not subjected to the aggressive exhaust gas.

A further possible way of protecting the electrodes consists in arranging them on a side of the base body which is inaccessible to particles. This can be done, for example, by embedding the base body in the side wall of the pipe which conducts the gas stream so that one of its sides, on which particles can become deposited, reaches into the gas stream, and the electrodes are arranged on its outer side which is in contact only with

ambient air, that is to say outside the gas-conducting pipe. The electrodes are in this case also well protected and the manufacture of the sensor is

simplified compared to embedding electrodes in the sensor material.

Equipping the sensor with a heating device results in a further advantageous embodiment variant. Thus, the sensor can easily be heated to different temperatures in order to carry out the method variants described above. The heating device can, for example, be a simple electrical heating resistance coil which is not in contact with the electrodes and which is mounted on the outside or embedded in the sensor.

In a further advantageous embodiment variant, the base body is provided with a catalytically active layer at least in the region which can be reached by particles. Oxides of various materials such as vanadium, silver, manganese or cerium are examples of suitable catalysts. Such a catalytically active layer reduces, for example, the ignition temperature of soot particles by approximately 150°C to 400°C. Therefore, in order to clean the sensor from a particle load by heating, it is no longer necessary to heat it so much, which reduces the thermal stress to which it is subjected, and thus its service life.

For a further description of the invention, reference is made to the exemplary embodiments of the drawings, in which:

figure 1 shows an exhaust pipe of a diesel internal combustion engine with a built-in sensor in a semi-sectional basic illustration,

figure 2 is a plan view of the sensor from figure 1 in the direction of the arrow II,

figure 3 is a circuit diagram of a resonant circuit with a connected sensor from figure 1,

figure 4 is a diagram for the voltage dropping across the sensor from figure 1 as a function of its ohmic resistance with wiring according to figure 3,

figure 5 is a diagram of the deviation of the resonant frequency from maximum resonant frequency of the resonant circuit according to figure 3 plotted against the change in resistance of the sensor,

figure 6 shows an alternative embodiment of a sensor with embedded electrodes in an illustration according to figure 1,

Patent claims

1. A method for monitoring the particle concentration in a gas stream (24), in particular of soot particles in the exhaust gas stream of an internal combustion engine, in which

- a sensor (4) which collects particles (28) is placed in the gas stream (24),
- the sensor (4) is integrated as a capacitive element (32) into an electromagnetic resonant circuit (31),
- the resonant circuit (31) is excited with an alternating voltage (42),
- a characteristic variable of the resonant circuit which can vary as a result of the particle load of the sensor (4) is determined as a reference value when the sensor is not loaded and the change in the characteristic variable which is brought about by the particle load compared to the reference value is determined,
- either the resonant circuit (31) being excited with alternating voltage (42) with a fixed frequency and fixed amplitude and the voltage which drops across the sensor (4) being determined as a characteristic variable or the resonant frequency of the resonant circuit (31) being determined as a characteristic variable.

2. The method as claimed in claim 1, in which the frequency of the alternating voltage (42) exciting the resonant circuit (31) is tuned to its respective resonant frequency, and the frequency of the exciting voltage (42) is determined as a characteristic variable.

3. The method as claimed in one of the preceding claims, in which, during the determination of the characteristic variable, the sensor (4) is heated to a temperature below the ignition temperature of the particles (28) in order to remove impurities adhering to said sensor (4).

4. The method as claimed in one of the preceding claims, in which, before the characteristic variable is determined, the sensor (4) is heated to a temperature above the ignition temperature of the particles (28) in order to remove a particle load.

5. A device for carrying out the method as claimed in one of claims 1 to 4, having a sensor (4) which is placed in the exhaust gas stream (24), is integrated as a capacitive element (32) into an electromagnetic resonant circuit (31) which is excited with alternating voltage (32), and collects particles (28), said sensor (4) having a nonconductive base body (12) made of porous material and two electrodes (14a, b) which are mounted spaced apart from one another.

6. The device as claimed in claim 5, in which the base body (12) is composed of ceramic.

7. The device as claimed in claim 5 or claim 6, in which the electrodes (14a, b) are embedded in the base body (12).

8. The device as claimed in one of claims 5 to 7, in which the electrodes (14a, b) are arranged on a side (26) of the base body (12) which is inaccessible to particles (28).

9. The device as claimed in one of claims 5 to 8, having a heating device (52) for the sensor (4).

10. The device as claimed in one of claims 5 to 9, in which the base body (12) is provided with a catalytically active layer.